Fixing Dark Energy: Ia Cosmology & GRBs in the New Paradigm

Discovering the Nature of Dark Energy: LAB 07-08

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Recent nearby Type Ia supernovae (SNe, *sing* SN), such as the *fourth* such (SN 2006mr) within the 26 short years of monitoring the merging elliptical/spiral galaxies comprising NGC 1316, and another (SN 2003fg) producing >1.2 solar masses of ^{56}Ni, have shown that the assumed paradigm for these objects – thermonuclear disruption of a single white dwarf star accreting material from a binary companion – upon which the inference of Dark Energy *critically* depends, is *invalid*. This casts significant doubt on both the existence of Dark Energy as implied by Type Ia SNe, and (after further inferences are drawn), neutron star-neutron star mergers as a *common* source of short, hard gamma-ray bursts (GRBs), a severe disappointment to the hopes of Earth-based gravitational observatories for frequent, easily detectable events. The correct paradigm for nearly 99% of all SNe *and* GRBs, is now likely merger-induced (MI) *core-collapse* (such as a merger of two carbon-oxygen white dwarfs with a total mass in excess of 1.4 solar), the possible source of the r-process and many cosmic rays. Therefore we propose to conduct a study of these two intimately related phenomena in the full light of the new, more likely paradigm, using the vast amount of data available from SN 1987A (the Rosetta stone for this process) and others. This study has the potential to: 1) fix the current systematic problems suspected in Ia cosmology under the new paradigm, 2) learn enough about the MI SN/GRB mechanism to quantify our understanding of it to unprecedented accuracy and, in the process, 3) facilitate and constrain (the currently prohibitively difficult and poorly constrained) calculations of this process, and 4) assist gravitational observatories in their attempts to detect such relatively frequent events (the *only* such ones). We will attempt to accomplish this latter by preparing for, and making feasibility observations, using the largest Earth-based telescopes available, of the nearest recent Type Ia/c SNe, both now guaranteed to be core-collapse events, usually at 1–3 years of age, to determine the rates of spin and spinning down of their ~2 ms, embedded, optical pulsar remnants. Finally, the study would more realistically assess the extremely unlikely, but grave threat that these events pose to our planet.

1. Scientific Background

1.1. The Problems with Type Ia Supernovae

The recent discoveries of the *fourth* Type Ia supernova (SN, *pl* SNe) in the whole 26 years of observations of the merging elliptical/spiral galaxies (SN 2006mr – see Figure 1),[1] comprising NGC 1316, and of another Ia (SN 2003fg – Howell et al. 2006), which produced >1.2 solar masses ($M_\odot$) of ^{56}Ni, have dealt a final death blow to the already highly unsatisfactory, assumed paradigm underlying cosmology determined by distant samples of these objects: the thermonuclear (TN) *disruption* (thus, of course, *no* core-collapse to any compact remnant) of a *single* white dwarf (WD – a $\sim$0.7 $M_\odot$ electron degenerate stellar remnant of TN ash, mostly carbon (C) and oxygen (O), about the size of the Earth), slowly pushed to the Chandrasekhar mass (1.4 $M_\odot$) by gradual accretion of He and/or H from a low mass,[2] binary companion star.[3] Thus once again, and rightly so, there is considerable doubt as to the very existence of "Dark Energy" (Perlmutter et al. 1999; Riess et al. 1998), for which the apparent anomalous dimming of Type Ia SNe is the *only* direct evidence (Conley et al. 2006), and doubt as well as to the precipitous rush to judgment concerning the parameters of the universe, otherwise known as "Concordance Cosmology."

1.2. The Correct Paradigm – Double Degenerate

The correct paradigm for Type Ia supernovae (SNe), is now likely "double-degenerate" (DD – Middleditch 2004,6 – hereafter M04 & M06): the merger of *two* stars, either as C-O

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[1]The dust lanes visible are a signature of a spiral galaxy, and are absent in nearly all other ellipticals. The three earlier SNe are 1980N on Nov. 30, 1981D on March 1, and 2006dd on June 19, 2006mr having been discovered on Nov. 5.

[2]The fact that no H or He is, by definition, *ever* observed in the spectra of Ia's, including none left on the surface of the exploding WD, or advected from the mass-donating companion star by the SN wind, *should* have raised a warning flag.

[3]As it takes at least a billion years for the low mass companion star to evolve to the point to where it starts to expand (and thus begin to accrete gas onto its WD companion) because He burning has initiated in its core, and only about a hundred million years for galaxies to pass through each other, the surfeit of Ia's in NGC 1316 is highly unlikely to have been produced by the previously suggested "standard" mechanism. Other arguments against the single WD paradigm include the lack of radio emission expected from a SN within a mass-transferring binary (Panagia et al. 2006), the ubiquitous high velocity features, the inverse relation between polarization and Ia luminosity, the unsuitability of cataclysmic variables as Ia progenitors, and the need for core-collapse in Ia's to produce the observed abundance of Zn (Middleditch 2006 and references therein).

WDs, or as cores of a common envelope (CE) Wolf-Rayet binary system (WR – see DeMarco et al. 2003). This is also the correct paradigm of up to 99% of *all* types of SNe, allowing for helium (He – Type Ib's & IIb's) and hydrogen (H – Type IIs), or neither (Type Ia's and Ic's) in the CE, as differences in outer envelopes matter little to the DD process. In Ia's, as in all DD SNe, some 1.4 $M_\odot$ is lost to core-collapse (CC) in producing a neutron star (NS) remnant. *Unlike* any other SNe *except* Ic's, the remaining overlayer of C and O, intimately mixed by the merger process and undiluted by H or He, is ignited on broad fronts upon initiation of CC, and burns and/or detonates very efficiently.[4] Because the WDs producing DD CC do not have strong magnetic fields (typically only several 100,000 Gauss), the NS remnant resulting from the merger will be only weakly magnetized (typically a few 10^9 G), but, because of conservation of the angular momentum of a merged, pre-CC WD with a 1.98 s rotation period (set by the branching of the Maclaurin and Jacoby solutions for the rotation), the resulting NS will be spinning at nearly 500 revolutions s^{-1}, consistent with the 2.14 ms signal observed from SN 1987A from 1992 to 1996 (Middleditch et al. 2000a,b).

1.3. SN 1987A – the Rosetta Stone

SN 1987A, the recent and well studied SN in the nearby Large Magellanic Cloud (LMC), as a DD Type II SN differs from the Ia DD scenario only in that it had H and He left in its CE, possibly resulting from a merger (Podsiadlowski & Joss 1989) of two stars of moderate mass ($\sim$8 $M_\odot$ each), producing the neutrinos heralding the birth of an NS (Bionta et al. 1987; Hirata et al. 1987). By now, the bipolarity of SN 1987A, one of the defining characteristics of DD CC, is clear, as shown in Figure 2 (Wang et al. 2002; M04). A polar blowout feature (PBF – the possible source of the "r-process" and many cosmic rays) approaches at about 45–55° off our line of sight. It partially obscures an equatorial bulge/ball (EB), behind which a part of the opposite, receding PBF is visible. The PBFs and EB are approximately equally bright.

1.3.1. The Implications for Ia's

Although the luminosity of a typical Ia will be dominated by the EB/TN ball (TNB) due to the high concentration of ^{56}Ni within it, its PBFs will have even higher velocities than

[4]This explains the high luminosity of Ia's above all other types of SNe, including the >1.2 $M_\odot$ of ^{56}Ni produced in SN 2003fg, without *inventing* "super-Chandrasekhar" mass WDs (Howell et al. 2006).

those of SN 1987A, due to their less massive CEs.[5] If we accept the validity of the calculations of TNBs (Pinto & Eastman 2001), that show these should obey the width-luminosity (WL) relation, then a subclass of Ia's viewed off their merger equators will exist that do *not* if their PBFs expose a fraction of their TNBs during the interval when Δm_{15} is measured, as seems likely.[6] Intrinsically very low luminosity members of this subclass, which fall 1–2 whole magnitudes (mag)[7] below the WL relation, can be excluded from distant samples because of an easily detected TiII shelf from 4,000–4,500 Å (possibly a hallmark of cooler burning which may be characteristic of intrinsically faint Ia's). However, unless the shelf itself is actually *only* a hallmark of inclination (which seems unlikely, but if so, would still have to be calibrated), higher luminosity Ia's viewed off the merger equator will still be significantly below the WL relation, but will *not* have the TiII shelf, and thus will be accepted into the distant, but likely not the local sample. We propose to correct for this effect, which need only average 0.25 mag to spuriously produce the entire Dark Energy effect in Ia cosmology.

So far, SN 1986J is the *only* known recent, nearby exception to the DD paradigm – a CC of a massive star resulting from Fe photo-dissociation catastrophe (PdC – thought to produce NSs, or black holes for the very rare progenitors with mass >25 $M_\odot$) – because it's luminosity at 15 GHz exceeds that of the Crab nebula by a factor of 200 (Bietenholz et al. 2004), and thus the compact remnant is a *strongly* magnetized NS/pulsar.[8] On the other hand, SN 1987A is likely to have been a DD SN, not just because of its bipolar explosion and side effects such as early polarization (Barrett 1988), but because of the blue supergiant (BSG) progenitor (Sanduleak 1969), and the details of the three inner rings (Morris & Podsiadlowski 2007), including the slow, 10 km s^{-1} expansion of the equatorial ring (ER – Burrows at al. 1995), characteristic of H gas at 10^4 K, lost from a common envelope system through one or both outer, mass-axis Lagrangian points.

The most remarkable feature[9] of SN 1987A was the "mystery spot" (MS), with a thermal

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[5]For DD SNe, the elements are mixed by the merger process, thus there is no amplification of velocity by inner layers of higher atomic number (Z) colliding with those of outer layers with lower Z. Thus less CE mass *does* result in higher ejection velocities, even if the CE contains only C and O.

[6]Unless, by some miracle, averaging over the bipolar geometry corrects itself, which must be considered highly unlikely, in view of the inverse relation between polarization and luminosity (M06).

[7]One magnitude is a factor of ∼2.5. There are exactly five magnitudes in a factor of 100, the amount by which a source would dim when it is ten times more distant.

[8]The origin of magnetic fields in NSs is still poorly understood, though it is believed that TN combustion in the massive progenitor to an Fe core is related. As a corollary, we note that models of SNe to date have not taken DD into account, and *certainly* have not been calibrated to an Fe PdC SN, such as 1986J.

[9]Not counting, for the moment, the 2.14 ms pulsed optical remnant, which also revealed a ∼1,000 s

energy of 10^{49} ergs, even 50 days *after* the CC event (Meikle et al. 1987; Nisenson et al. 1987), and separated from the SN photosphere "proper" by some 0.06 arc s *along the axis of its DD merger* toward the Earth, some 45–55 degrees off our line of sight. The approaching polar beam/jet produced by SN 1987A, which collided with what is thought to be previous polar ejecta (PE) some 20 light-days distant from the SN along this axis, may be *generic* to the DD process. Through its interaction with the overlaying common envelope (CE) and/or PE it produces the wide variation in gamma-ray burst (GRB)/X-ray flash properties observed from DD SNe of sufficiently low inclination to the line of sight.

There are many other conundrums of SNe and GRBs that the DD paradigm explains with *ease*, and part of the purpose of the requested funding is to explore them in greater detail. DD mergers of C-O WDs explain the millisecond pulsars (MSPs) in Population II, and in particular, the large overabundance of MSPs discovered in the non-core collapsed (nCCd) globular clusters (GCs) such as 47 Tuc, over the last 20 years (Lyne et al. 1987; Chen et al. 1993).[10] Per above, DD explains the small amount of ^{56}Ni produced by Type IIs and Ib's,[11] because their C and O layers[12] have been diluted by He and/or H by the mixing involved in the merger process. It also predicts that Fe PdC SNe, excluding those very rare, sufficiently massive ones that go on to produce black holes, will produce more than the usual 0.06–0.12 $M_\odot$ of ^{56}Ni typical of Type II and Ib SNe, and will be brighter as a consequence of this, in addition to the energy input from the strongly magnetized NS remnants that we think these produce.

The DD CC process manages to produce what some astronomers have described as "hypernovae," "supranovae," and "collapsars," and others as "MS(s)," "GRB afterglows," and "Type II-P plateaus." Calculating this is presently too ambitious, because so little is known about it. It is by far the most frequent energetic event in the universe, occurring at the SN rate of one per second, and we will spend a good part of this half century figuring it out. With Dark Energy in need of further verification through SN studies, and LIGO

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precession (Middleditch et al. 2000a,b). Since a prototypical, faint, dim, thermal neutron star remnant (DTN) has been discovered in Cas A (Tananbaum et al. 1999), representing what PSR 1987A will look like after another 300 years, and other pulsars have since been observed to precess (Stairs et al. 2000), this candidate is no longer controversial.

[10]Recycled pulsars weighing 1.7 $M_\odot$, in the CCd GC, Ter 5 (Scott Ransom 2006), have removed high accretion rate from contention as a alternative mechanism to produce the MSPs in the nCCd GCs.

[11]The non-DD explanation of the difference between these and Ia's is that the electron Fermi level is high enough near the proto-neutron star to inhibit burning to elements with equal numbers of neutrons and protons, such as ^{56}Ni. In DD CC, however, the Fermi energy at the overlayer is likely much lower.

[12]Merged massive stars with H and He, progenitors of Type II SNe, can have a few $M_\odot$ of C and O!

currently running at design sensitivity, it's time to start.

1.3.2. The Gamma-Ray Burst Connection

If we had taken the H and He out of the envelope of the progenitor of SN 1987A, Sk -69°202, the beam/jet produced by its DD CC process which, in turn, produced the MS, would likely be indistinguishable from (and indeed *would be*) a full-up GRB. This realization, together with the observation that no soft, long-duration GRBs (ℓGRBs) have been found in elliptical galaxies, together with the further realization that the DD process *must* dominate (as always, through binary-binary collisions) by a large factor, the NS-NS mergers in these populations, even when requiring enough WD-WD merged mass to produce CC, leads to the *inescapable* conclusion that the DD process produces hard, short GRBs (sGRBs) prior to their passage through the CE and/or PE, the means by which they become ℓGRBs. This is an amazing fact, as the fraction of sGRBs with durations shorter than 120 ms is well above 10% – way too large to be all soft gamma repeaters (SGRs)[13] or NS-NS mergers – and the light travel time across the Earth's 12,756 km diameter, about the size of a WD, is still 42 ms. Thus, given that the sGRBs in ellipticals are due to nearly naked mergers of CO-CO WDs, the initial photon spectrum of ℓGRBs is *known*!

In addition, of the *three* different classes of GRBs, ℓGRBs, sGRBs, and the intermediate time, softest GRBs (iGRBs – see Figure 3), as recently classified by Horváth et al. (2006), most sGRBs occur from DD WD-WD merger without CEs or PE, ℓGRBs pass through at least the PE (necessary for small angle deviations to produce 100s of s of delay), and usually the CE (which, in addition to the PE, can soften the burst), while iGRBs pass through red giant (RG) CEs, but little or no PE, possibly the result of a merger of two stars with very unequal masses, the possible cause of SN 1993J, which had a red supergiant (RSG) progenitor (Podsiadlowski et al. 1993).[14] These could provide more CE material than the totals of CE and PE for mergers of stars with more nearly equal masses, possibly the blue supergiant (BSG) progenitor of 1987A, Sk -69°202, and thus generate bursts that are sometimes softer even than ℓGRBs (Fig. 3). They easily provide more emergence delay (T_{90}) than sGRBs, because of the beam's/jet's passage through an RSG envelope, consistent with the $\sim$10 s

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[13] SGRs are NSs with very strong magnetic fields, $\sim 10^{14-16}$ G – the likely source of their soft bursts – and many are anomalous X-ray pulsars (AXPs) with rotation periods near 6 s. About 5% of sGRBs are thought to be due to SGR events.

[14] At 1.6 and 1.0% (Trammell et al. 1993) the early polarization of SN 1993J was *twice* that of the 0.9 and 0.4% observed from SN 1987A (Schwarz & Mundt 1987; Barrett 1988), consistent with even *more* axiality than that of 1987A.

limit for T_{90} and its tradeoff with spectral hardness (H_{32}) for the iGRBs plotted in Fig. 3. This is still obviously much less delay than the 100s of s allowed by the much more distant (∼20 light days) PEs of the ℓGRBs associated with mergers of stars with more nearly equal masses.[15] Like ℓGRBs, the initial photon spectrum of iGRBs is also known.

1.3.3. The Type Ic SN Connection

Occam's razor alone would argue that Ic's are Ia's viewed from one of their poles, where the bright signature of ^{56}Ni and the nuclear ash consisting of S, Si, Fe, are hidden from view because of the bipolar nature of the DD CC explosion, given sufficient mass in the overlayer (see further below). Assuming they weren't would beg the question of what Ia's viewed from their poles *would* actually look like, and, given that DD already produces GRBs, there is *no need* for *another* mechanism for stars less compact than NSs. The extreme velocities which led to inventions of "hypernovae," "supranovae," "collapsars," and other exotica are possibly due only to the direct, early view of the PBFs, and a light (but non-absent) load of material in the overlayer. Their association with actively star-forming galaxies (ASFGs) can be explained by the formation of binaries. As might be expected, Ic's are also nearly absent from ellipticals, likely due to insufficient material in the overlayer to shroud the TN products, consistent with the "leaner" Ia's typical of these non-ASFGs noticed by everyone (Hamuy et al. 2000; Sullivan et al. 2006; Wang et al. 2006). Since no SNe have been found in some GRBs with optical afterglows (Gal-Yam et al. 2006; Fynbo et al. 2006; Della Valle et al. 2006; Gehrels et al. 2006), Ia DD CC can be very lean indeed.

1.3.4. The Gravitational Radiation Connection

That the vast bulk of sGRBs in ellipticals are due to DD CC and, to a much lesser degree, SGRs, is also a cold, hard fact for LIGO and other Earth-based gravitational observatories, as they can almost never assume that these are the result of the more (or what we think should be more) easily detectable NS-NS mergers. Thus for the Earth-based gravitational

[15]A one degree offset of a beam over the 20 or so light days distant PE of SN 1987A would delay the arrival of the non-prompt part of the GRB by about three minutes. The fluence of *both* the non-prompt and prompt parts of such off-axis ℓGRBs are suppressed, the first by scattering in the PE, the second by being off axis by the time it emerges from the CE, frequently leaving both roughly equally attenuated. This scenario also explains why the two ("precursor" and "delayed") have similar temporal structure (Nakar & Piran 2002). Negligible spectral lag for late (∼10–100 s) emission from "spikelike" bursts (Norris & Bonnell 2006) can be explained in terms of small angle scattering off the PE, without invoking extreme relativistic Γ's.

observatories, the DD SN process is almost always the *only* game in town. However, the short duration of such bursts is also a very hopeful fact, in as much as it could be the signature of a very violent final settling into the spinning NS configuration, which, in and of itself could produce detectable gravitational radiation out to a distance of 10 Megaparsecs (Mpc – 3,260,0000 light years),[16] enabling sensitive searches for chirps of increasing/decreasing spin frequency preceding/following the CC events.

1.3.5. Yes, these things really can fry us

From a great distance with little or no warning. There is a slight advantage to belonging to a galaxy with high metallicity, as the CE and PE will be more opaque to gamma-rays because of such content. However, the GC, M4, is only 2 kiloparsecs away (kpc – 3,260 light years), is very non-centrally condensed, and thus had to have merged two WDs in order to make its 11 ms pulsar, B1620-26, producing a GRB in the process, possibly with no CE or PE to soften the blow. An apparent GRB fluence of 10^{54} ergs from M4 (lasting a few s) would deposit the equivalent of 3.4 *days* of sunlight, or about 100,000 times the solar flux for 3.4 s. Imagine the *entire* sky as bright as the sun. This would be unpleasant. Further detailed studies of SNe and GRBs in the light of the new paradigm should lead to a more accurate assessment of the danger.

[16] Dropping 0.5 $M_\odot$ 10^6 cm in a gravitational field of 10^{14} cm/s^2, which can be considered as a radian of orbital motion in a system spinning at 500 revolutions/s, would take 2 ms/(2 π) = 300 μs, and produce a strain parameter, h, of 5×10^{-21} at 10 Mpc. The final settling of the NS is an unknown, but, as this shows, distantly detectable GR events from DD CC can not yet be ruled out.

Fig. 1.— The merging elliptical and spiral galaxies of NGC 1316.

2. Experimental Approach

2.1. Beams, Jets, GRBs and Systematics in SNe

Sometimes it's hard to see the forest for the trees. This is certainly true for SN 1987A, for which there is a lot of very detailed data (the trees) from which we hope to determine the physics of DD CC (the forest). SN 1987A was a Type II-P SN, which means that it rose to an early plateau before curving over to the more typical ^{56}Ni decay slope, making this "bump" wider than it would otherwise be (see Figure 4). It also had a jet/beam which impacted the PE, producing the MS which was observed, via speckle interferometry, to be separated from it by about about 0.06 arc s some 30, 38, and 50 days after CC, by two independent groups (Meikle et al. 1987; Nisenson et al. 1987), at a level near 7% of the stellar light at Hα (6562 Å), corresponding to a total energy content of about 10^{49} ergs, with 3% of this eventually radiated in the optical. The MS direction coincides with the bipolar angle of 194 degrees visible in Figure 2 (the minor axis of the ER is nearly due south, at 179 degrees). The geometry is such that it takes light only about *eight* extra days to hit it and continue on to be observed from the Earth (Burrows et al. 1995). In this interpretation, the first part of the linear rise in luminosity following the minimum, the "plateau" of Type II-P SNe, is due to (indeed *is*) the MS itself, the differences in the early part of II-P plateaus being due to inclination and distance/structure to/in the PE.

Very early measurements of SN 1987A can be interpreted in the light of the beam/jet which had to exist and have *some* luminosity in the days prior to colliding with the nearest PE. Evidence for this sequence of events can been seen in a plot of data from the International Ultraviolet Explorer (IUE) Fine Error Sensor (FES) and CTIO as shown[17] in Figure 5. There is a drop from the initial flash to below mag 4.35 before recovering by day 3.0, which can be interpreted as the breakout of the faster, hotter, central part of the beam/jet from its more outer, cooler, and roughly cylindrical layers. This declines to a minimum near mag 4.48 around day 7.0, interpretable as free-free cooling of the optically thin beam/jet, proportional to the square of time, which is drawn extrapolated back to CC, when the beam optical luminosity can be estimated to be 1.6×10^{41} ergs s^{-1}. It then shows a slight hump to day 8.0, *the same delay predicted from the MS geometry,* interpretable as the leading light from the beam/jet scattering in the PE to produce about 2×10^{39} ergs s^{-1} for a day or so. A three day gap follows in the FES observations, after which a linear trend of rising luminosity is evident, which extrapolates back to the point at day 9.5, interpretable as the particles of the beam/jet hitting the PE, with the fastest particles traveling at 0.8 c.

[17] The CTIO V band center occurs at 5,500 Å, as opposed to 5,100 Å for the FES.

Since we know that by day 30, the MS could only have amounted to some 8% of the light from 87A (6% at 533 nm by day 38 – Nisenson et al. 1987), and the FES data imply that the light had risen some 75% from the minimum, the light from the 87A photosphere proper (PP) *must* have risen significantly from day 9.5 to 30 in Fig. 5. Considering that the cooling time of the beam/jet, deduced from the data between days 4.0 and 6.5 in Fig. 5, has to be between one and two days, and even when combined with the PE can't be much longer, the light from the MS had to have reached a maximum *between* days 11 and 30. Indeed, there is a "hump," between days 9.0 and 19.0, in the V band data from CTIO, confirming the association of this light contribution with the MS. The hump is less noticeable in the FES data, perhaps due to band difference. A decrement near day 20 is visible in both bands, but also appears as a spike of $\sim 10^{39}$ ergs s^{-1} in the B, R, and I CTIO bands (Fig. 4), possibly due to penetration through the PE and/or light hitting yet other ejecta (Nisenson & Papaliolios 1999). In any case, the roughly constant, low percentage of light from the MS between days 30 and 50 may be due to the further penetration/collision of the beam/jet into/with the PE. The CTIO point just before the decrement, a rough maximum for the MS luminosity, corresponds to an excess above the minimum (near day 6.0) of 5×10^{40} ergs s^{-1}, about 23% of the total optical flux of 2.1×10^{41} ergs s^{-1}.

Thus a vast amount of detailed photometric data for SN 1987A is ripe for modeling under this paradigm. Middleditch has experience with novel photometric systems (Middleditch & Cordova 1982), and the analysis program is still lying around. We hope to learn how much its beam/jet has been modified by passing through the CE, and thus determine the initial *particle* content for the vast bulk of GRBs, *the last remaining piece of the GRB beam/jet puzzle*.[18] Other constraints on the beam/jet include X-ray upper limits, and UV, optical, and IR spectra. Many have invoked magnetic fields to explain breaks in the spectra of GRBs (see, e.g., Mészáros 2006). This may or may not be an unnecessary complication (see, e.g., González et al. 2003), as magnetic interaction is over after a fraction of a ms for the weakly-magnetized, 2 ms pulsars formed. However, direct collisions of 0.8 c protons will leave electrons with relativistic Lorentz factors of 4–5, and for sufficiently low densities (the number density of the ER is about 10^4 cm^{-3}, scaling homologously inward to the PE would raise this only to 10^7), synchrotron radiation losses with ambient magnetic fields may dominate free-free losses (Cen 1999). Middleditch and a student will model the existing data in detail, and this effort should be mostly finished within a year.

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[18] The big one that remains, is, of course, the "how?"

2.2. Observational Effort

Fortunately, DD CC events are likely to be generic, with most producing MSPs with spin periods near 2 ms, which, if SN 1987A is any guide, will be optical pulsars for at least a few years. Knowing their spin periods more exactly, even three years after the event, will almost certainly help us detect their gravitational signatures. Therefore, it is critical to mount a program of feasibility observations of the nearest SNe with the largest Earth-based optical telescopes.[19] If a number of such observations fail, then the observing will wait for a closer candidate,[20] a bigger telescope (such as the Thirty Meter Telescope), or both. In any case, SN 1986J, with 200 times the Crab nebula luminosity at 15 GHz, will be a collateral target in these observations. Keck 10-m time is available to Dr. Jerry Nelson, the Keck project scientist, and we would hope to make observations within the next three years, telescope scheduling being subject to several factors that are difficult to control. For targets in the Southern Hemisphere, SN 1987A is also a logical, collateral target, made a moon-bright, largest telescope target by the glowing of ejecta impacting the ER. Consistent detection of optical pulsations from SN 1987A with such telescopes could lead to a highly productive, longterm monitoring program of this unique object, *which has not been observed with any instrument capable of detecting rapid pulsations for more than a decade, and has* **never** *been so observed with any telescope of aperture >4 meters.* Whether one accepts the 2.14 ms candidate pulsar or not, these observations of SN 1987A *must* be made, and sooner rather than later, in part because they have the potential to impact Ia cosmology.

Since the Crab pulsar produces four $L_\odot$ in optical pulsations, SN 1986J might produce 800 $L_\odot$ in optical pulsations if these scale with the 15 GHz luminosity. With one of the Keck 10-m telescopes, the sensitivity to pulsed optical light under the best possible circumstances is near 500 $L_\odot$ at the 10 Mpc distance to the host galaxy, NGC 0891. However, we have no idea as to what the extinction was for 1987A during the four year span from 1992, Feb. to 1996, Feb. when it was more or less reliably detected. We only know that it faded by 1–2 mag after 6.5 years of age. The best earlier limit, at 1.5 years of age, was near 21.6 $L_\odot$ for the V + R band, characteristic of the Si photodiode (Pennypacker et al. 1989), but the extinction could have been very high this early.

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[19] It is likely that SN 1987A did produce optical pulsations as strong as 25 solar luminosities ($L_\odot$) some 5.0 to 6.5 years of age (Middleditch et al. 2000a,b).

[20] Or rather, a *better* candidate, i.e., an intrinsically fainter Ia with a high drop of velocity (gradient) wrt time, which is an indicator of a sufficiently low inclination to the merger axis (but not so low as to fall outside of the pulsar beam), so that there is a better chance of seeing past, rather than through, the high opacity Fe group elements.

Given all of the uncertainties, a 500–1,000 $L_\odot$ luminosity can not be ruled out for young remnants of merger SNe. This may mean that we likely only have a window of a few years when the most nearby Ia/c extragalactic SNe have any chance of being detected, even by the largest ground-based telescopes now available. Although it is unusual to request funding for observations which may well fail, if we don't do so, a window of opportunity to detect these sources could come and go without our having any knowledge of it.

It has been a decade since high time resolution observations have been made of *any* young SN, particularly none of SN 1987A (as mentioned above), due to various reasons, including the frenzy of Ia cosmology efforts at nearly all large telescopes on the planet. Partly as a consequence, the real problem we face is instrument commissioning at the largest telescopes, none of which have anything quite so (apparently) "useless" as a high speed photometer. The solution is a more versatile instrument developed by the Galway group, the TRIFFID 2-dimensional photometer, which consists of a beam splitter which divides the incoming light into two light paths, B and VRI, achieved with dichroic filters (Shearer et al. 1997,8). The B beam is separately focused onto a L3 CCD Andor iXon DV887 detector (DQE:$\sim$50% in the B band), which has a 512 $\times$ 512 16 micron pixel field, thinned and back illuminated so it has >90% qe above 5,000 Å, and >50% above 4,000 Å. The max readout speed is $\geq$200 fps. The VRI beam is focused onto three avalanche photodiodes (APD; DQE's: R[70%]). Adjustments may have to be made for the higher counting rates expected because of the brighter ER of SN 1987A and larger telescope apertures. Dr. Andy Shearer is the PI for the instrumental effort, and we expect it to be ready to travel within two years. Only Shearer's travel and shipping costs will impact this proposal.

Over that two year period, we will initiate an observational campaign using Very Long Baseline Interferometry of the nearest recent Type Ia/c SNe. Observing at the largest baselines with maximum participating antenna, we will obtain images at 5, 8 and 15 GHz corresponding to a resolution of $\sim$1 mas, or $\sim 10^4$ AU at 10 Mpc, sufficient to assess the visibility of a compact core, consistent with a compact object, as determined for SN 1986J (Bietenholz et al. 2004). Dr. Aaron Golden is the PI for the VLBI program, having used both the VLBA and EVN to determine pulsar parallax and resolve emission structures on radio active ultracool dwarfs. Only Golden's travel costs, under $5K/a will impact this proposal.

2.2.1. On Site Data Analysis

Computers have greatly improved over the past decade and a half. It would therefore make sense to install a suite of analyses into a portable/laptop computer. This may need an addon fast memory in order to perform very large Fast Fourier Transforms without thrashing the disk(s). A suite of programs written by former student Scott Ransom already exists, so it would make sense to use this, and modify it as needed. One desired algorithm would resample at a candidate's frequency including its suspected time of arrival (toa) modulation characteristic of some (but not all) forms of pulsar precession. Experience with candidate signals from SN 1987A near 2.14 ms has shown that the power recovered in the harmonic with a suspected toa modulation will be much less/more due to very narrow, intrinsic pulses/very large amplitude toa modulation (Middleditch et al. 2000b). Middleditch will work with Shearer on the analysis suite, and we would expect this to be mostly ready within two years.

2.3. Calculations

The recent events in the nearby universe have also rendered calculations of Type Ia SNe with the invalid paradigm, such as "gravitationally confined detonation" (Plewa et al. 2004) or "delayed detonation" (Khokhlov 1991), into so much "computational science fiction." One of the goals of this proposal is to guide the calculations back toward reality, as this can not fail to benefit computational simulation efforts at the national labs. RAGE calculations may be useful for certain aspects of the beam/jet of SNe. Middleditch and a graduate student will work on the calculations which we expect to be substantially complete within a year.

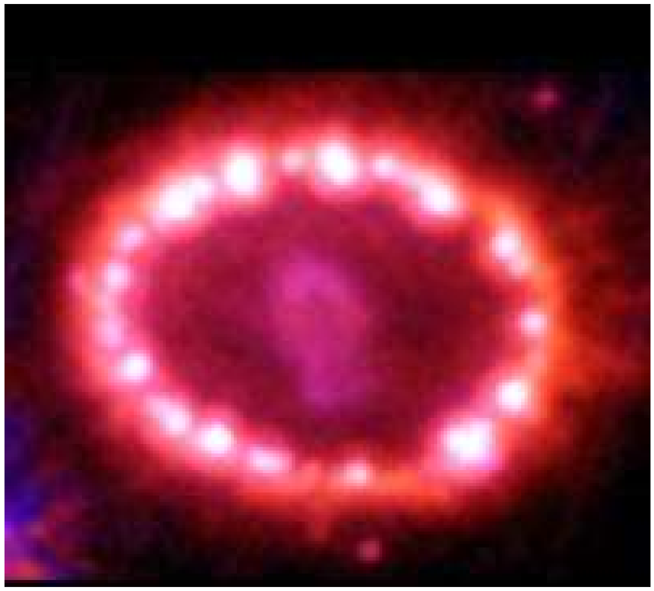

Fig. 2.— SN 1987A as of 2003 November 28, as viewed with the HST (NASA, R. Kirshner, & Wang et al. 2002).

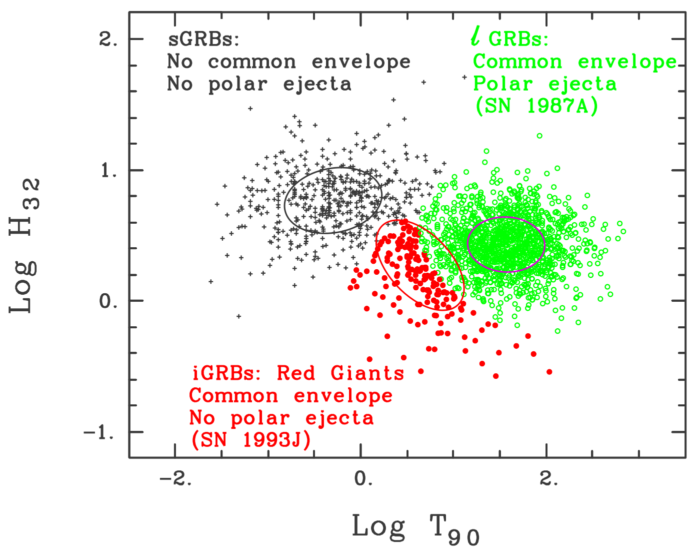

Fig. 3.— After Horváth et al. (2006), the GRBs from the BATSE catalog (Meegan et al. 2001) are scattered in duration (T_{90})-hardness (H_{32}) space.

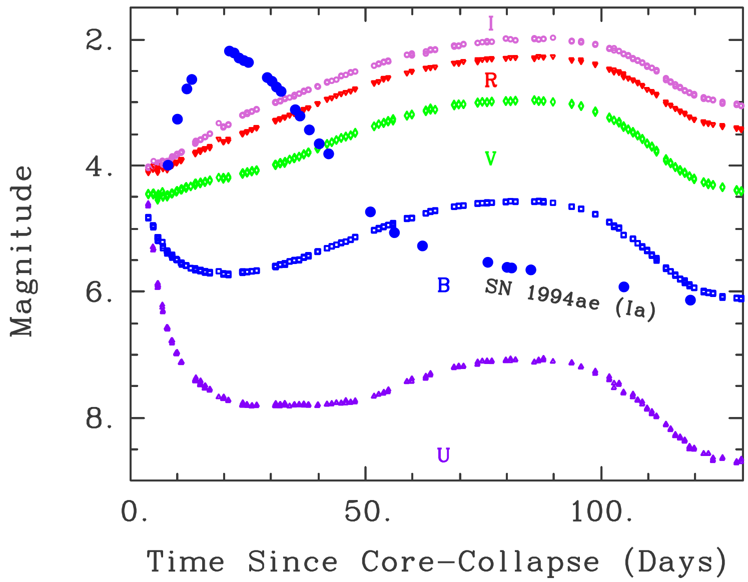

Fig. 4.— The early light curve of SN 1987A from CTIO (Hamuy & Suntzeff 1990) in U, B, V, R, and I, and the B light curve from the Type Ia SN 1994ae (filled circles – from Riess et al. 1999), offset by -11 mag.

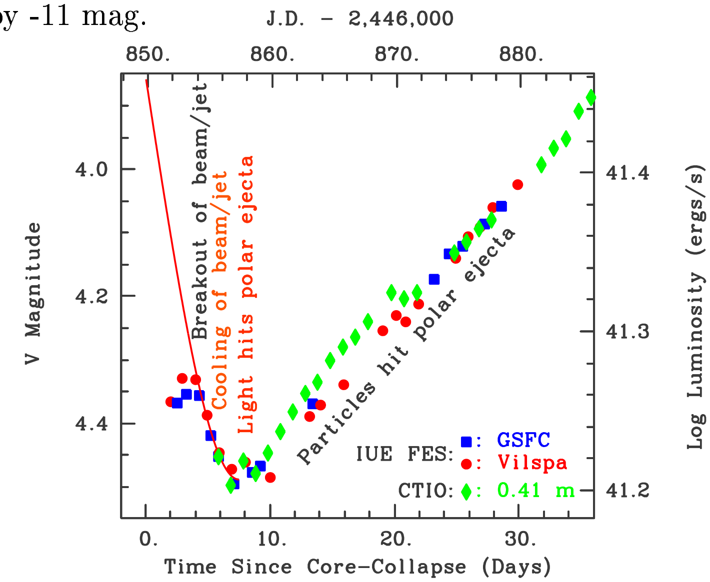

Fig. 5.— After Wamsteker et al. (1987 – with data included from Sonneborn & Kirshner 1987a,b), the very early light curve of SN 1987A, as observed with the FES of IUE and the CTIO 0.41-m (Hamuy & Suntzeff 1990). Data points taken at Goddard Space Flight Center, and the Villafranca Station in Madrid, Spain, are marked. The CTIO points have been adjusted in time by +1 day, and the FES V magnitudes have been reduced by 0.075 to match the CTIO data after day 23.

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Table 2. Glossary of Abbreviations

Abbreviation	Meaning
Å	Angstrom – 10^{-8} cm
ASFGs	Actively Star-Forming Galaxies
BSG	Blue Supergiant
C	Carbon
CC	Core-collapse (collapse to an NS or black hole)
CCd	Core-collapsed (cores of GCs)
nCCd	non-Core-collapsed (cores of GCs)
CE	Common Envelope
CTIO	Cerro Tololo Inter-American Observatory
DD	Double-Degenerate (MI CC of two WDs)
DQE	Discrete Quantum Efficiency
DTN	Dim Thermal Neutron Star
EB	Equatorial Bulge/Ball
ER	Equatorial Ring (of SN 1987A)
Fe	Iron, element 26
FES	Fine Error Sensor (of IUE)
fps	frames per second
G	Gauss (unit of magnetic field strength, Earth: $\sim$1 G)
GC	Globular Cluster
GRB	Gamma-Ray Burst
iGRB	intermediately long GRB
ℓGRB	long, soft GRB
sGRB	short, hard GRB
H	Hydrogen
He	Helium
IUE	International Ultraviolet Explorer
kpc	kiloparsec (3,260 light years)
$L_\odot$	Solar Luminosity ($\sim 4\times10^{33}$ ergs s^{-1}
LIGO	Laser Interferometric Gravitational-Wave Observatory
LMC	Large Magellanic Cloud
mag	Magnitude (5 per factor of 100)
mas	milli-arc second

Table 2—Continued

Abbreviation	Meaning
Δm_{15}	The increase in SN mag between max and +15 days
MI	Merger-Induced
$M_\odot$	Solar Mass (2×10^{33} gm)
Mpc	Megaparsec (3,260,000 light years)
MS	“Mystery Spot”
MSP	Millisecond Pulsar
NGC	New General Catalog (of galaxies)
NS	Neutron Star
O	Oxygen
PBF	Polar Blowout Feature (see Fig. 2)
PdC	Photodissociation Catastrophe
PE	Polar Ejecta
PP	Photosphere Proper (excludes MS)
RG	Red Giant
RSG	Red Supergiant
S	Sulfur
SGR	Soft Gamma Repeater
Si	Silicon
SN	Supernova
SNe	Supernovae (*pl* of SN)
Ti	Titanium
TiII	Singly-ionized Titanium
TN	Thermonuclear
TNB	Thermonuclear Ball
WD	White Dwarf
WL	Width-Luminosity (between SN hump width & luminosity)

Table 3. Curriculum Vitae

	John Middleditch[a]
	February 12, 2007
Personal Details	
Address	CCS-3 MS-B265,LANL, Los Alamos NM 87545
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Education	
1964-68	B. S. physics, honors,
	California Institute of Technology
1968-75	Ph. D. physics, University of California, Berkeley,
	1976, Thesis advisers, Eugene Commins/Jerry Nelson
Positions	
1988.35 - present	Technical Staff Member, LANL (C-3, CIC-19,3, CCS-3)
1980.75 - 1988.35	" " " (NIS-2)
1976.83-80.75	Physicist P4, Lawrence Berkeley Laboratory
1975.92-76.83	Visiting Professor at the Asiago Astrophysical
	Observatory of the University of Padua, Italy
Research Interests	Rapid time variability in astronomical sources
	pulsars: binary, X-ray, radio/optical ms, QPOs,
	Galactic center, supernovae, gamma-ray bursts
	Image reconstruction/Computational techniques
Professional Societies	American Astronomical Society
Accomplishments	First mass and spin sense measurements of an NS
	First inclination-independent measurement of an
	unresolved binary system (P$\sim$2500s) and second
	spin sense measurement of an NS (4U1626-67)
	Discovery of a 50 ms young optical pulsar in the LMC
	SPARTAN-1 imaging analysis of Galactic Center
	Simultaneous co-discovery of rapid QPO in X-ray sources
	Discovery of the first pulsar (3 ms) in a GC (M28)
	Discovery of the first pulsar in a GC with a $\frac{\partial P}{\partial t} < 0$

Table 3—Continued

	John Middleditch[a] February 12, 2007
	" a 2.14 ms precessing optical psr in SN 1987A slowing via GR
	" the (2^{nd}) fastest young pulsar (62 Hz) in any supernova remnant
	First accurate glitch prediction for any pulsar (PSR J0537-6910)
LANL Activities	2005-06 RAGE code test support & diagnostics
	2005-07 CMPC for CCS-3
	2004-05 W88 Certification Team
	1998-07 ADC for CCS-3
	1993-98 Large Data Sets Specialist
	1993-94 Housecalls Program
	1992-04 Modeling Support for AGEX Surety/HEVR Programs
	1990-97 Coach/adviser NM Technet Supercomputing Challenge
	1988-99 FFT algorithm specialist, C-3, CIC-3
	1988-97 Observational astronomer C-3
	1984-88 Imaging specialist for SPARTAN 1
	1982-88 Support astronomer, SPARTAN-1, URA, SSO-2
	1980-88 Observational astronomer SSO-2

[a]Selected Publications (not in References): J. Middleditch, 2006 "Predicting the Starquakes in PSR J0537-6910," The Astrophysical Journal, 652, 1531-1546. F. E. Marshall, E. V. Gotthelf, W. Zhang, J. Middleditch & Q. D. Wang 1998 "Discovery of an Ultra-fast X-ray Pulsar in the Supernova Remnant N157B," The Astrophysical Journal (Letters), 499, L179-182. J. Middleditch & C. R. Pennypacker, 1985 "Optical pulsations in the large Magellanic Cloud Remnant 0540-69.3," Nature, 313, 659-661. J. Middleditch, K. O. Mason, J. E. Nelson, & N. E. White 1981 "4U 1626-67 - A prograde spinning X-ray pulsar in a 2500 s binary system," The Astrophysical Journal, 244, 1001-1021. J. Middleditch, & J. Nelson, 1976 "Studies of optical pulsations from HZ Her/Her X-1: a determination of the mass of the neutron star," The Astrophysical Journal, 208, 567-586.